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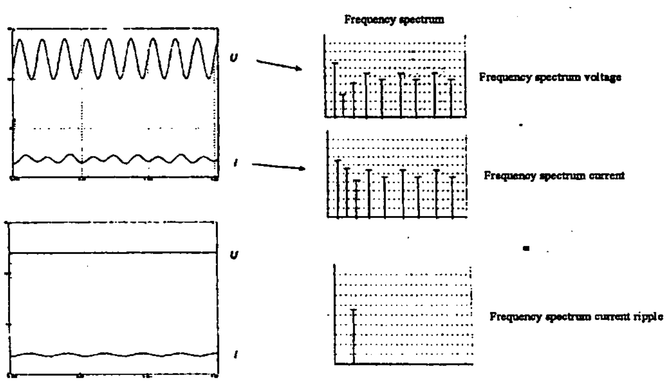
(54) Title: **PROCESS FOR DETERMINING THE ROTATIONAL POSITION OF THE DRIVE SHAFT OF A COMMUTATED DIRECT CURRENT MOTOR**



(57) Abstract: This invention relates to a method for determining the frequency of the current ripple contained in the armature current signal of a commutated d.c motor. Said frequency is determined by calculating the difference between the result obtained through spectral analysis of the armature current signal and the result of a further spectral analysis of an electric motor operating variable.

Process for Determining the Frequency of the Current Ripple Contained in the Armature Current Signal of a Commutated Direct Current Motor

The invention concerns a process for determining the frequency of the current ripple contained in the armature current signal of a commutated direct current motor.

The armature current signal of a commutated direct current motor comprises a direct component and a ripple component superimposed on the direct component. The ripple component arises when the direct current motor is operated as a consequence of the interaction of the magnet (field), the armature winding, and the commutator of the direct current motor. This expresses itself in a transient change in the induced voltage, which produces the ripple content in the armature signal. The current peaks contained in the armature current signal – referred to below as current ripples – occur when the armature rotates, and have a frequency corresponding to the number of collector bars. For example, if the armature has ten collector bars, the armature current signal accordingly has ten current ripples that can be detected in it. Thus, counting the current ripples can give information about the actual rotational position of the direct current motor's armature, and thus regarding the element driven by it within its predetermined segment of travel. To accomplish this, the analog armature current signal is digitized to make it possible to perform a corresponding count. The number of current ripples counted in a certain time interval is the current ripple frequency, which gives information about the actual rotational speed of the direct current motor.

To make it possible for current ripple detection to be performed with as few errors as possible, the analog armature current signal is appropriately conditioned before and possibly after it is digitized, to suppress interference. To condition the armature current signal, filtering is done, which is in the form of low-pass filtering and/or frequency filtering. For example, such a signal conditioning process is described in DE 195 11 307 C1. The aim and purpose of such signal conditioning processes is to provide a precise armature current signal that is as free as possible of interference, so that the current ripple contained in this conditioned armature current signal can then be evaluated. To determine the position, the ripples are counted, since the counter result gives direct information about the actual rotational position of the drive shaft or the armature of

the direct current motor. The current ripples contained in the armature current signal are usually counted using minima or maxima determination algorithms, or algorithms to determine the zero crossings.

However, the previously known signal conditioning and correction processes can only sufficiently eliminate or minimize interference contained in the armature current signal if the current ripples contained in the armature current signal are distinct in the armature current signal. It is problematic, if not even impossible, to evaluate the current ripples contained in the armature current if they have interference superimposed on them, which can also make themselves apparent by the fact that the current ripple signal can be modeled as an interference [signal] whose frequency and amplitude change randomly, as a consequence of voltage fluctuations, for example.

Therefore, starting from the prior art which has been discussed, the invention is based on the task of proposing a simplified process for determining the frequency of the current ripple contained in the armature current signal of a commutated direct current motor, which also makes it possible to perform a reliable frequency or rotational speed determination if the armature current signal has interference superimposed on it.

This task is solved according to the invention by the fact that the frequency of the current ripple contained in the armature current signal is determined by taking the difference between the result of a spectral analysis of the armature current signal and the result of another spectral analysis of an electric motor operating parameter.

The process according to the invention involves determining the current ripple frequency in the armature current signal by taking the difference between the results of two spectral analyses performed independently of one another. At least one of the results of the two spectral analyses is obtained from the armature current signal. The result of the other spectral analysis is a corresponding one based on another electric motor operating parameter, for example the motor voltage. In this case, the spectral analyses, which have been performed, for example, by means of a fast Fourier transform of the armature current signal or of the motor voltage signal into its

respective frequency domain, exhibit interference in the same way. By contrast, the current ripples make themselves apparent more or less exclusively, but at least to a clearly greater extent, in the spectral analysis which involved transforming the armature current signal, however not in the result of the spectral analysis obtained from the motor voltage signal. Taking the difference of the results of these two spectral analyses eliminates the interference components which are apparent to the same extent in the results of the two spectral analyses, with the result that only the actual value of the current ripple frequency remains for further evaluation. Thus, this subtraction eliminates all oscillations which are not caused by commutation, but rather originally come from distortions in the voltage signal. There is no effect due to the frequency components having any possible phase shifts caused by the respective operating state of the direct current motor, since the direct current motor does not produce any shift in the frequency components. Instead, it adds new ones, namely the current ripple. Therefore, the process according to the invention is not only able to determine the frequency of the current ripple contained in the armature current signal even if it has interference superimposed on it. Rather, a current ripple identification and a following rotational speed and position determination of the direct current motor's armature shaft are also possible if voltage fluctuations occur. In such an embodiment in which the difference calculation uses the results of spectral analyses, first of the armature current signal and second of the motor voltage signal, the difference calculation can be done simultaneously and thus with the data of the same sampling time point.

Another sample embodiment provides that both spectral analyses to be subtracted from one another use the armature current signal, in which case it should be ensured that the armature current signal on which the spectral analyses are based has been recorded in different operational states of the direct current motor. For example, the spectral analyses can be performed with the direct current motor [operating] at a different rotational speed. The spectral analyses are then based on armature current data which is separated in time. This embodiment assumes that the interference is approximately constant within the time interval between when the first and the second spectral analyses are performed; it is expedient for this interval to be small. The current ripple frequency can be determined each time the direct current motor is started up, for example.

In theory, such a calculation can be made at every cycle of the digital sampling of the signal

curves entering into the evaluation. In direct current motors which are always in operation for a short time, such as for example, window raising motors in a motor vehicle, it is expedient and also sufficient for the current ripple frequency to be determined every time the direct current motor is started up.

The frequency of the current ripple contained in the armature current signal determined in the way described above can be used directly, as a consequence of its proportionality to the rotational speed, to make it possible to determine the rotational angle of the direct current motor's armature shaft or the position of an element driven by it.

Changes as a consequence of the direct current motor's operating state result in a change in the frequency of the current ripple contained in the armature current signal. Consequently, changes in the frequency of the current ripple can be attributed directly to a change in the rotational speed of the direct current motor.

To perform the spectral analysis, the analog armature current signal can first be digitized and then transformed into its frequency domain by means of a fast Fourier transform. These process steps can be designed not to be very computationally intensive. This also has the consequence that it is very easy to perform these calculations at every point in time of the digital sampling of the analog armature current signal, so that the rotational angle of the direct current motor's drive shaft or armature shaft can be determined with a very high time resolution. Consequently, this process can also be used for correction processes which require the direct current motor's actual rotational speed. In particular, if the process steps are performed in step with the digital sampling, this process makes it possible to capture changes in the operational state virtually in real time, and thus also take them into consideration in determining the actual value of the rotational angle.

In contrast to the prior art, the claimed process does not involve performing any frequency filtering, but rather determines the actual value of the current ripple frequency directly by blanking out frequency components which might be superimposed on the armature current signal as interference. In this process, the observed current ripple frequency is evaluated directly,

without this theoretically requiring a separate prior current ripple detection or special signal conditioning. Therefore, this process is also especially suitable to be able to perform a sensorless position determination in commutated director current motors with fewer requirements on their quality by taking advantage of the current ripple contained in the armature current.

However, not only can the process according to the invention provide a way of determining and monitoring the actual value of the current ripple's frequency when a direct current motor is operated, but rather this operating frequency of the current ripple contained in the armature current signal can also be monitored for abrupt changes in the current ripple frequency. When missed and/or double ripples occur, there is an abrupt change in the actual value of the current ripple frequency, so that if such an abrupt change is then detected in the actual value of the current ripple frequency, it is then possible to make a correction in the current ripple counter result, and thus of the current position determination.

Detection of such an abrupt change in the actual value of the current ripple frequency can be subjected to a plausibility check, for example about the duration of the frequency change or about the frequency jump, in order to avoid, in this way, an interpretation of frequencies not induced by current ripple. Thus, such a correction process makes it simple to correct for missed and/or double ripples, without this necessitating costly and computationally intensive algorithms to detect missed and/or double ripples.

The invention is explained below once again using the figures. The figures are as follows:

Figure 1: A diagram showing how the difference is formed between the results of two spectral analyses to determine the current ripple frequency in the armature current signal of a commutated direct current motor.

In a commutated direct current motor the motor voltage and motor current signal is monitored. The signal curves of the motor voltage and of the motor current are reproduced in the top left diagram in Figure 1, in which the motor voltage curve is marked with *U* and the motor current curve is marked with *I*. The irregularity of the armature current signal *I* shows that it contains not

only the current ripple signal, but that it also has other oscillations superimposed on it, for example, the ripple content of a motor vehicle electrical system, if the direct current motor is used in a motor vehicle as a window raising motor, for example.

The oscillations which the armature current signal *I* has superimposed on it, for example those of the ripple content in the electrical system, are also apparent in the motor voltage curve *U*. The current ripples contained in the armature current signal / are not contained in the motor voltage signal *U* or, if they are, they are very much more attenuated. These relationships are now used to determine the current ripple frequency. To accomplish this, the motor voltage signal *U* is transformed into the frequency domain, by way of a fast Fourier transform, for example, so that a spectral analysis can be performed. A corresponding transform is also performed of the armature current signal / into the frequency domain. The two frequency spectra of the motor voltage and the motor current are plotted at an appropriate place on the right, next to the above-mentioned diagram. The two frequency spectra reflect the oscillation frequencies involved in bringing about the respective curves *U*, *I*. Subtracting these two frequency spectra from one another eliminates the interference contained in the two frequency spectra, so that the result retains the current ripple frequency, which is what is decisive in the armature current signal. This current ripple frequency can then undergo a subsequent evaluation, for example, for a determination of the actual value of the rotational speed of the direct current motor and for a downstream determination of the position of its drive shaft or of an element driven by it.

At the bottom left of the diagram in Figure 1 is a plot of the motor voltage *U* which has had the interference, for example the ripple content in the electrical system, purged from it, and the correspondingly purged armature current signal *I*. The armature current signal / now reproduces exclusively the ripple content of the current ripple. This diagram makes clear only the result of the difference taken between the two frequency spectra used in this sample embodiment.

Monitoring the current ripple frequency according to rotational speed allows the monitoring of changes in the current ripple frequency; the interference superimposed on the current ripple frequency by such a change is ignored. Such interference which is caused by the commutator also changes its frequency when the rotational speed changes, so that in theory this interference

can also be observed.

If missed ripples or double ripples occur, the frequency of the current ripples changes abruptly, so that this can also easily be detected with the described process. Missed or double ripples appear for only a short time, and can be identified in the interference spectrum due to this property, for example.

Claims

1. Process for determining the frequency of the current ripple contained in the armature current signal of a commutated direct current motor, **characterized in that** the frequency of the current ripple contained in the armature current signal is determined by taking the difference between the result of a spectral analysis of the armature current signal and the result of another spectral analysis of an electric motor operating parameter.

2. Process according to Claim 1, **characterized in that** the analog armature current signal is digitized before the spectral analysis is performed.

3. Process according to Claims 1 or 2, **characterized in that** to perform the spectral analysis the digitized armature current signal is transformed into its frequency domain by means of a fast Fourier transform.

4. Process according to one of Claims 1 through 3, **characterized in that** an electrical motor operating parameter which enters into the further spectral analysis is the motor voltage.

5. Process according to one of Claims 1 through 3, **characterized in that** the electric motor operating parameter which enters into the other spectral analysis is also the armature current signal, with the two spectral analyses being performed in different operating states of the direct current motor.

6. Process according to one of Claims 1 through 5, **characterized in that** the frequency of the current ripple contained in the armature current signal is determined every time the direct current motor is started up.

7. Process according to one of Claims 1 through 6, **characterized in that** the frequency of the current ripple contained in the armature current is used to determine the rotational position of the direct current motor's drive shaft by first determining the frequency of the

current ripple in the armature current signal, and then using this frequency to determine the actual value of the direct current motor's rotational speed, and from the rotational speed, the current position of the direct current motor' drive shaft.

8. Process according to Claim 7, **characterized in that** the process steps are performed at each point in time of the digital sampling of the analog armature current signal.

9. Process according to Claim 7 or 8, **characterized in that** during the operation of a direct current motor, the current ripple that occurs is monitored for changes in its frequency, and a further evaluation is performed by considering the difference between it and one or more previously determined current ripple frequencies.

10. Process according to Claim 9, **characterized in that** during the operation of a direct current motor the actual value of the frequency of the current ripple contained in the armature current signal is monitored for abrupt changes in this frequency, and if such an abrupt change is detected in the actual value of the current ripple frequency, a correction is made in the current ripple counter result.

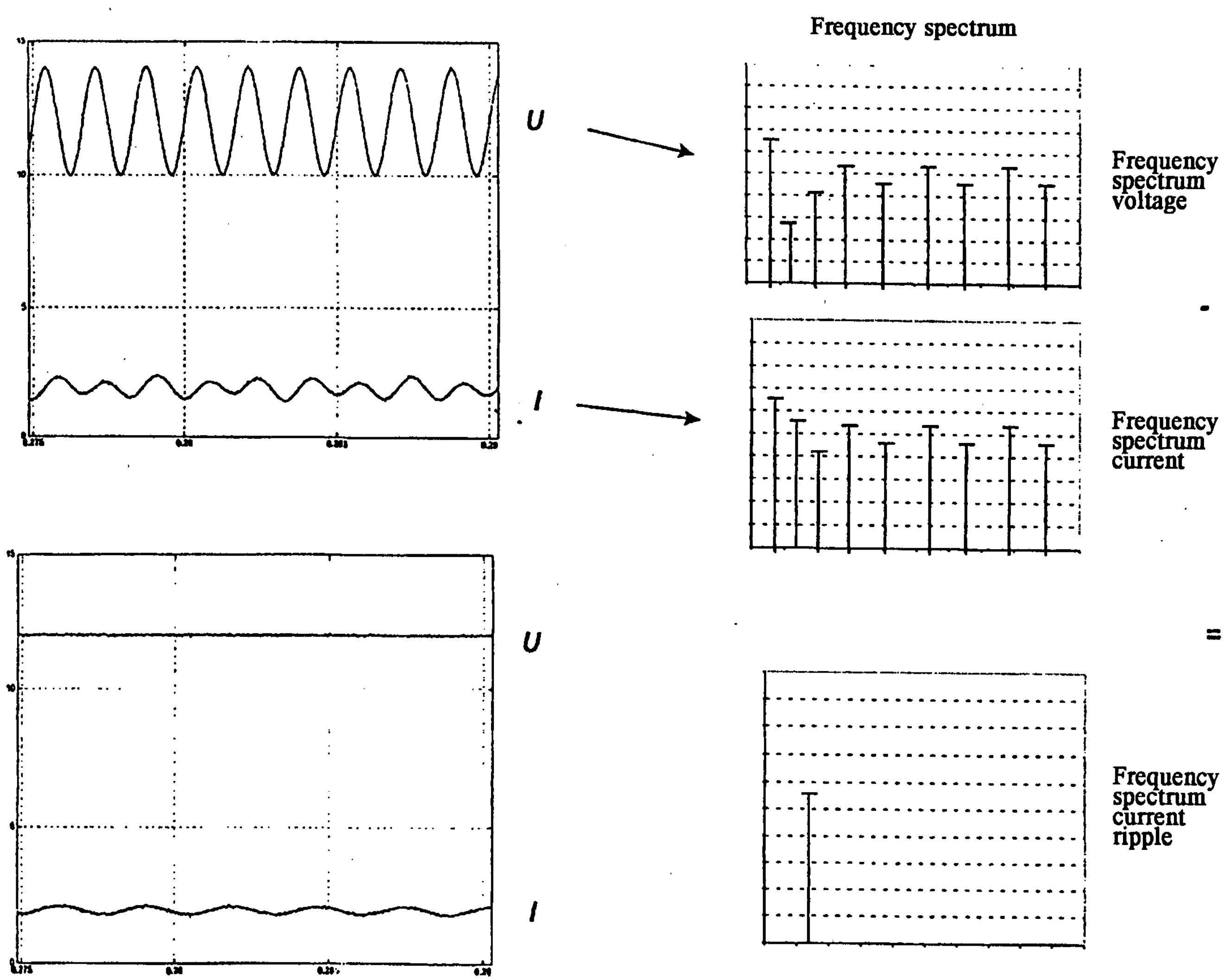

Frequency spectrum
U
I
U
I
Frequency spectrum voltage
Frequency spectrum current
Frequency spectrum current ripple

Fig. 1